Investigation on the combustion properties of refuse derived fuel in an internally circulating fluidized bed

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Abstract. An internally circulating fluidized bed (ICFB) was applied to investigate the behavior of refuse derived fuels (RDF) incineration. The temperature distribution along bed height was measured by the thermocouple and the pollutant emissions in the flue gas were measured by Fourier transform infrared spectrometry Gasmet DX-3000. In the tests the concentrations of the species CO CO_2 HCl N_2O SO_2 were measured online. The experimental results showed that the RDF could combust steadily in the fluidized bed. The concentrations of the CO HCl N_2O in flue gas were higher than the values of national environmental standards.

Introduction

Municipal solid waste (MSW) comprises combustibles, biomass with high moisture content and noncombustible. Modern disposal technologies of MSW comprise landfill, compost and incineration. The incineration disposal technology has such advantages that it disposes quickly, the workshop needs small area, the reduction ration is high and some matter can be recycled. So it has attracted more and more interesting from governments and researchers. But the high content of element Cl S N in the MSW can release in the form of HCl NO_x SO_x during the combustion. And these pollutants probably cause the serious second pollution. Also the acid gas pollutants may erode the boiler, heat exchanger and so on. The effect of these pollutants on the environment and people's health is also very harmful. The above factors limited the wide use of MSW incineration technology in the world. A hopeful treatment method of gaining maximum income is MSW integrating disposal technology according to the economical analysis, by which its three sorts of waste are disposed separately. That is to say, combustibles (e.g., plastic, paper, textile, etc.) used to incinerate, biomass (e.g., kitchen waste and wood, etc.) to compost, and noncombustibles (e.g., brick, ash, metal, etc.) to landfill or recycle. In this process of MSW disposal, combustibles are made as refuse-derived fuels (RDF), kitchen waste as fertilizer and metal as recycling matter. This may bring considerable profits for an integrating disposal plant. Therefore, now such MSW disposal plants are being built in China. The production of RDF is growing as a potential fuel, and the pollution from RDF combustion should be a concern.

Several studies[1, 2] have been reported on the pyrolysis dynamics and combustion properties of the RDF in all kinds of burners. Also the emissions of pollutants (CO SO_2 NO_x HCl) PCDDs/Fs and heavy metals have been investigated and evaluated during the cofiring of RDF and other solid fuels [3-8].

The incineration experiments of RDF were firstly done in a laboratory internally circulating fluidized bed (ICFB). The temperature distribution along the bed height and the emissions of pollutants (CO SO_2 N_2O HCl C_xH_y) were measured online.

Experiment

The RDF used in the experiment was come from the product line of 6 tons/day built by cooperation of Institute of Engineering Thermophysics and Japanese company IHI.

The bed material consisted of 0.5-1.0mm average diameter quartz sand mixed with a minor quantity of the fuel ash remaining in the bed after combustion. The air velocity is 6.0 u_{mf} in the fluidized zone with high air velocity (u_{mf} is the minimum fluidized velocity) and 2.5 u_{mf} in the moving zone with low air velocity.

Table 1 shows the fuel properties in the form of average values from several samples. Because the waste is fully dried in the preparation process of RDF, almost no water is contained in the RDF. The heating value of RDF is so high that it is equivalent to the value of some bituminous coals. From Table 1, it is found that the content of slement hydrogen oxygen and chlorine in RDF is extremely high. The higher hydrogen and oxygen content occurs because of the organic matters in waste. Also, the higher chlorine content arises from chlorine in PVC (polyvinyl chloride) plastic and waste paper as well as from salt in food. The shape of RDF is a small rod with a diameter of 15mm and the length of 30-45 mm.

Table 1 RDF properties

Fuel	proximate analysis（%）				ultimate analysis（%）						heating value (MJ/kg)
	FC_d	V_d	M_{ar}	A_d	C_d	H_d	O_d	N_d	S_d	Cl_d	$Q_{net,ar}$
RDF	9.35	73.48	0	17.17	57.24	9.09	14.39	0.21	0.26	1.64	24.1

Fig. 1 illustrates the schematic of the internally circulating fluidized bed incinerator. The main body of ICFB consists of air chamber segment, dregs discharging segment, dense phase bed, transition segment, secondary air segment and gas emission outlet segment. The air chamber segment consists of air-cup, air distribution plane, air chamber and pressure expanding segment. Ten air-cups are uniformly installed on the declined air-distribution plane, six of them for high-speed airflow zone and the other for low-speed airflow zone. The bed material in high-speed airflow zone flows acutely so the zone is called flowing bed and the bed material low-speed airflow zone drops slowly so the zone is called moving bed. The cross section of the dense phase zone is 500 × 240 mm, and the height is 1000mm. In the furnace, the dense phase zone changes gradually into the freeboard with the cross section of 800 × 280 mm and the height of 3500 mm.

All the tests were performed under the same operating conditions with high-speed primary air 60m³/h, low-speed primary air 20m³/h and second air 40m³/h. Bed was preheated by other fuels to 800-900℃ then the fuel was fed into the bed by hand with 15kg/h or so.

The pilot plant is equipped for the continuous measurement of temperature and pressure drop at different height of the reactor. Continuous extractive sampling of the exhaust gases was used for the analysis of the major gas components. Gas concentrations were measured by Gasmet DX-3000 infrared flue gas analyzer made in Temet company of Finland. This analyzer can measure 30 gas pollutants on-line and the measurement accuracy is 1%. The sampling place is in the top of hearth, where the temperature is 500-650℃, and the heating temperature of flue gas sampling tube is 180℃.

Results and discussion

Fig 2 indicates the gas temperature profile along the bed height during the RDF combustion in the ICFB. From the figure it can be found that the fluidized air under the bed bottom was preheated 433 K. After it enters the bed via the inclined air distributor and bubbling cups, it was heated quickly by the high temperature carbon particles and the bed material particles. So its temperature can reach 1123-1173 K in the dense phase zone and decreases gradually in the transition segment. With the entering of secondary air, the temperature in freeboard began to increase for the combustion of volatile and unburnout gas. After the burnout of these matters, the temperature began to decrease along the bed height gradually. With the increasing of the heat loss, the exit temperature was only 523-573K.

Fig 3 shows the concentrations of H_2O CO_2 and O_2 with varied time during the combustion of RDF in bed. The average concentrations of H_2O CO_2 and O_2 are 8.75%, 7.78% and 7.5% respectively. The concentrations CO_2 and O_2 fluctuate sharply because the species and release rate of volatile in RDF with high content (>70%) fluctuate during combustion. Thus the fluctuation of CO_2 and O_2 concentration is one of problems which must be considered in the incineration treatment of wastes. The range of H_2O concentration is from 4% to 10%. For the high H content in RDF, lots of H_2O releases although there is almost no moisture in RDF.
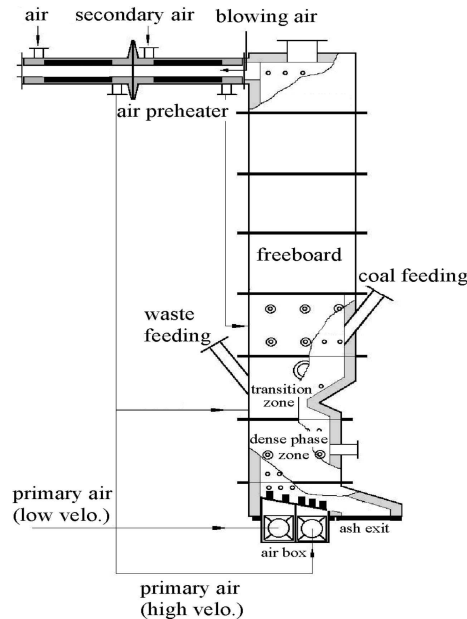

Fig 1 The scheme of the ICFB

The concentrations of HCl SO_2 N_2O and C_xH_y (including CH_4 C_2H_2 C_2H_4 C_2H_6 and C_6H_6) with varied time during the combustion of RDF in bed are shown in Fig 4. From this figure it can be seen that the average value of SO_2 is 200mg/m^3 and it is lower than the national standard (260mg/m^3) because the content of the element S in the RDF is very low. While the average concentration of HCl is 675mg/m^3 and it is so high that it is much higher than the national standard (75mg/m^3). The reason is that the element Cl content in the RDF is so high that it reaches 1.64% and most of Cl releases in the form of HCl. Under the high temperature the high HCl concentration may erode the metal of the combustion chamber, super-heater, re-heater, pre-heater and so on which may decrease the life of the boiler. Also under some certain conditions the HCl and SO_2 in the air can form the acid rain which is very harmful to the agriculture and industry. So the high content of HCl and SO_2 in the flue gas is one of serious problems that should be considered in the treatment of RDF incineration. One of the solutions is adding the additives with Ca during the preparation of RDF. The Ca^{2+} can react with HCl and SO_2 during the combustion of RDF which maybe reduce the formation of the HCl and SO_2. Another way is to add the additives with Ca during the combustion of RDF in the bed. This is the next work we will plan to do in the lab.

The average concentrations of N_2O and C_xH_y are 70mg/m^3 and 90mg/m^3 respectively. The high content of NO_x and C_xH_y are also the serious problems that should be considered in the incineration of RDF.

Fig 5 shows the concentration of CO with time during the combustion of RDF in bed. In ICFB, air with high or low velocity enters the different bed zone. Gas velocity above the high velocity zone is also very high and the oxygen is insufficient in the low velocity zone which will affect the gas mixing in the freeboard. The poor gas mixing will inhabit the CO oxidation. Also the higher volatile matter in the RDF will cause lots of volatile release after the RDF heated in the bed. Some unburned CO will be measured in the flue gas and this also causes the high concentration of CO in flue gas.

Conclusions

The bed temperature and the concentrations of H_2O CO CO_2 O_2 HCl SO_2 N_2O and C_xH_y were investigated during the incineration of RDF in the ICFB. The gas temperature profile along the bed height shows that the RDF can incinerate steadily in the ICFB. During the incineration of RDF in the bed, the concentrations of CO HCl and N_2O were higher than the values of national environmental standard while the concentration of SO_2 is lower. So the incineration tests of RDF in the ICFB show that the gas pollutants in the flue gas were so high that it can't be incinerated in the bed purely. One probably method is to co-combust the RDF and the other solid fuels such as coals and biomass.
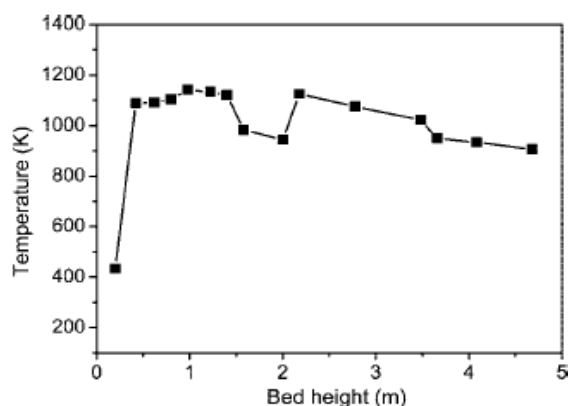
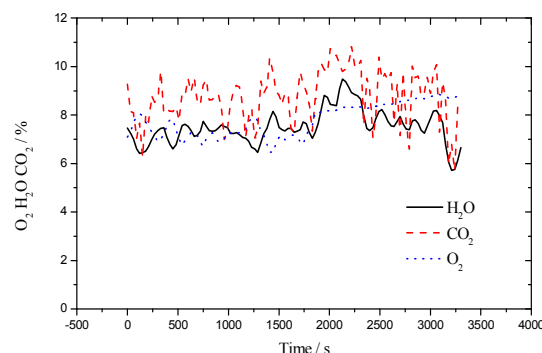Fig 2 Gas temperature profile along the bed height
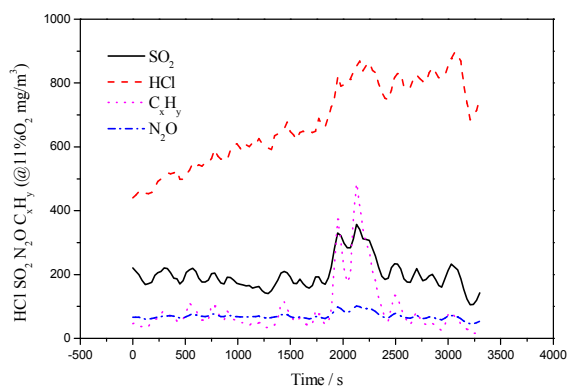
Fig 3 H_2O CO_2 and O_2 emissions with time

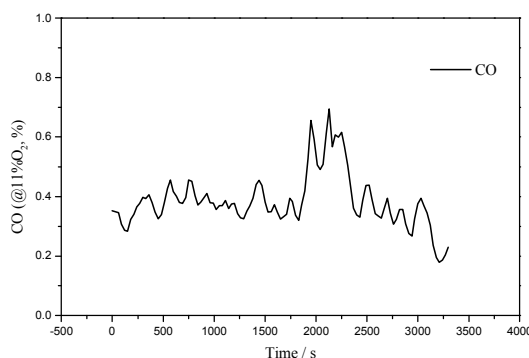Fig 4 HCl, SO_2, N_2O and C_xH_y emissions with time

Fig 5 CO emissions with time

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